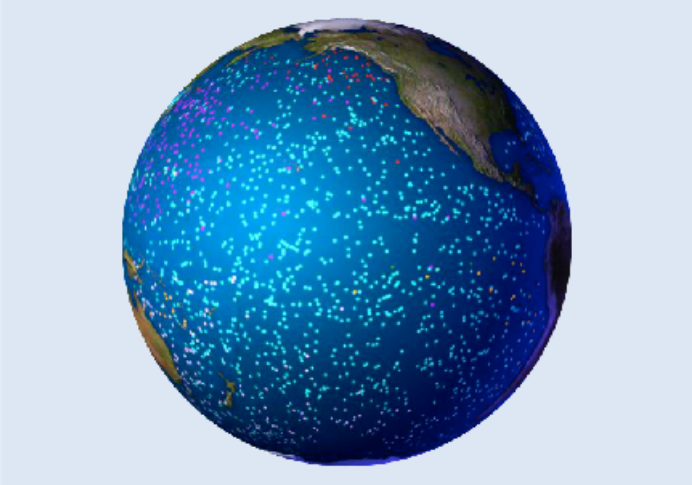

Argo and Ocean Heat Content: Progress and Issues

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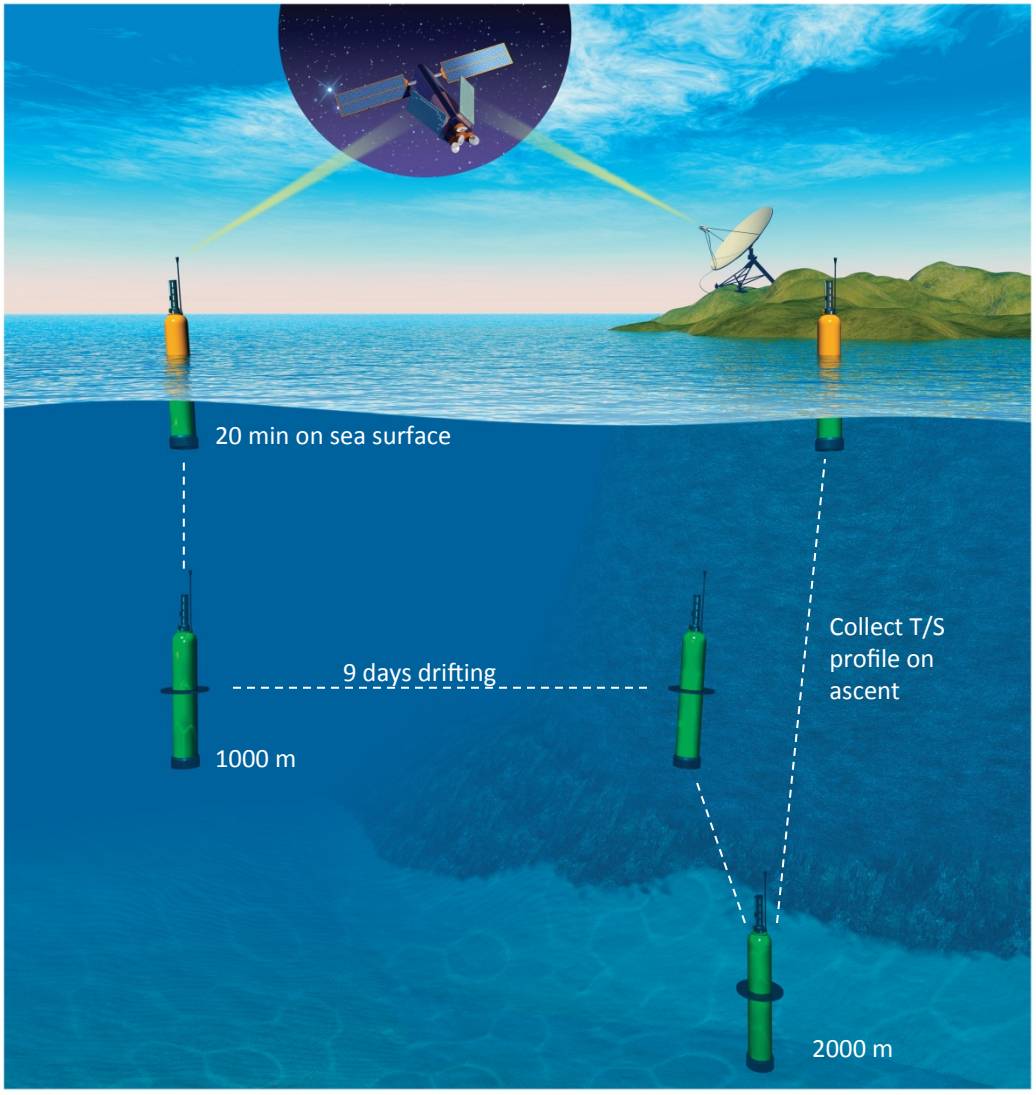
October 2013, CERES Meeting

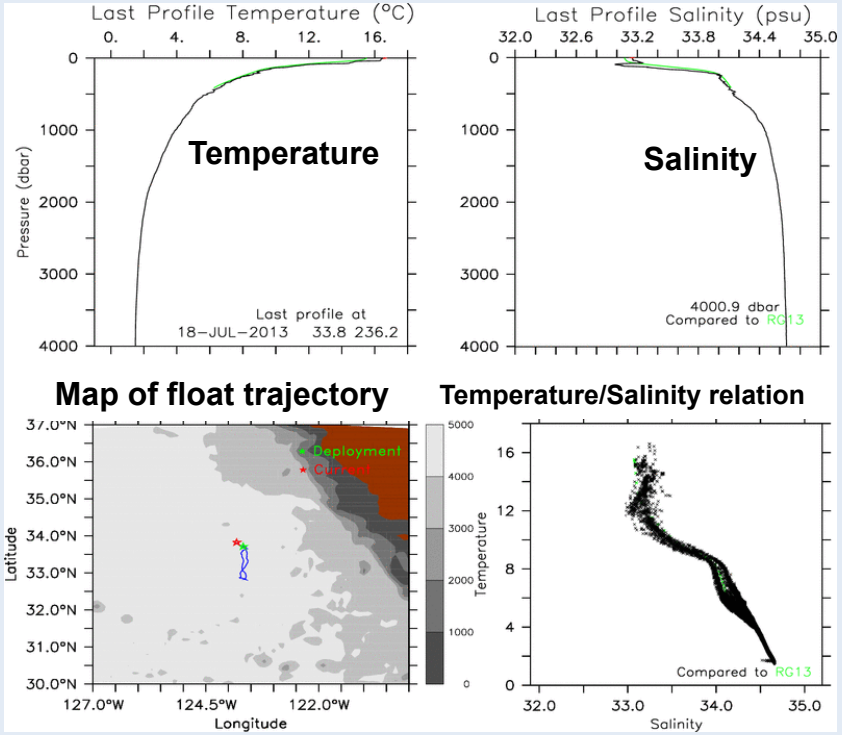
Outline

- What makes Argo different from 20th century oceanography?
- Issues for heat content estimation: measurement errors, coverage bias, the deep ocean.
- Regional and global ocean heat gain during the Argo era, 2006 – 2013.

How do Argo floats work?

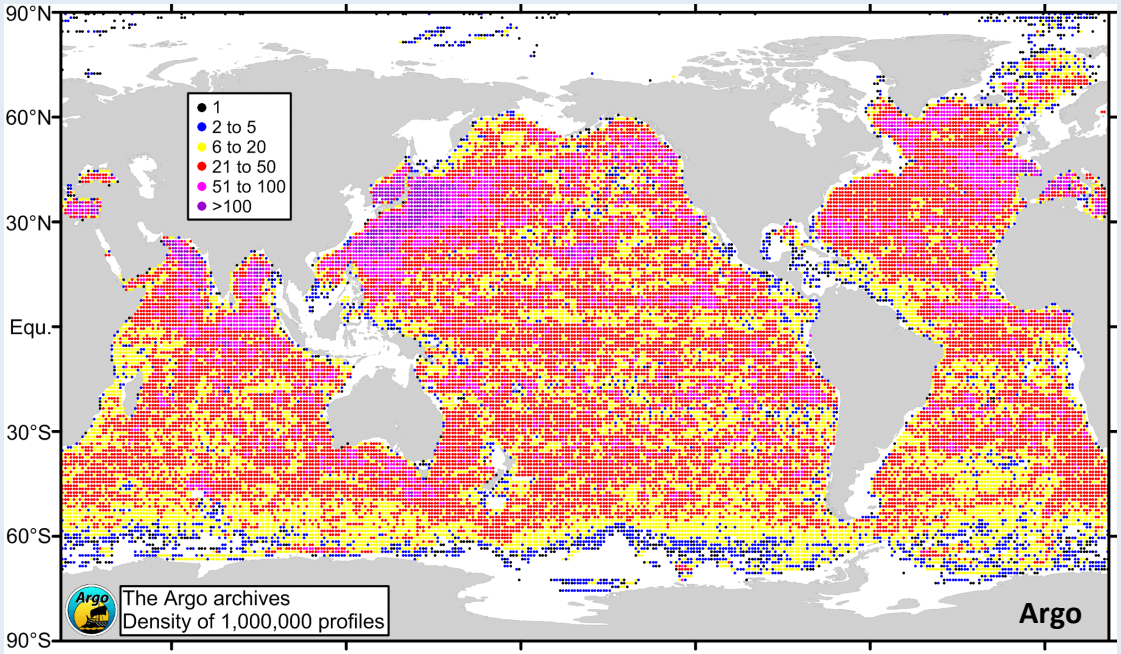
Argo floats collect a temperature and salinity profile and a trajectory every 10 days, with data returned by satellite and made available within 24 hours via the GTS and internet (http://www.argo.net) .

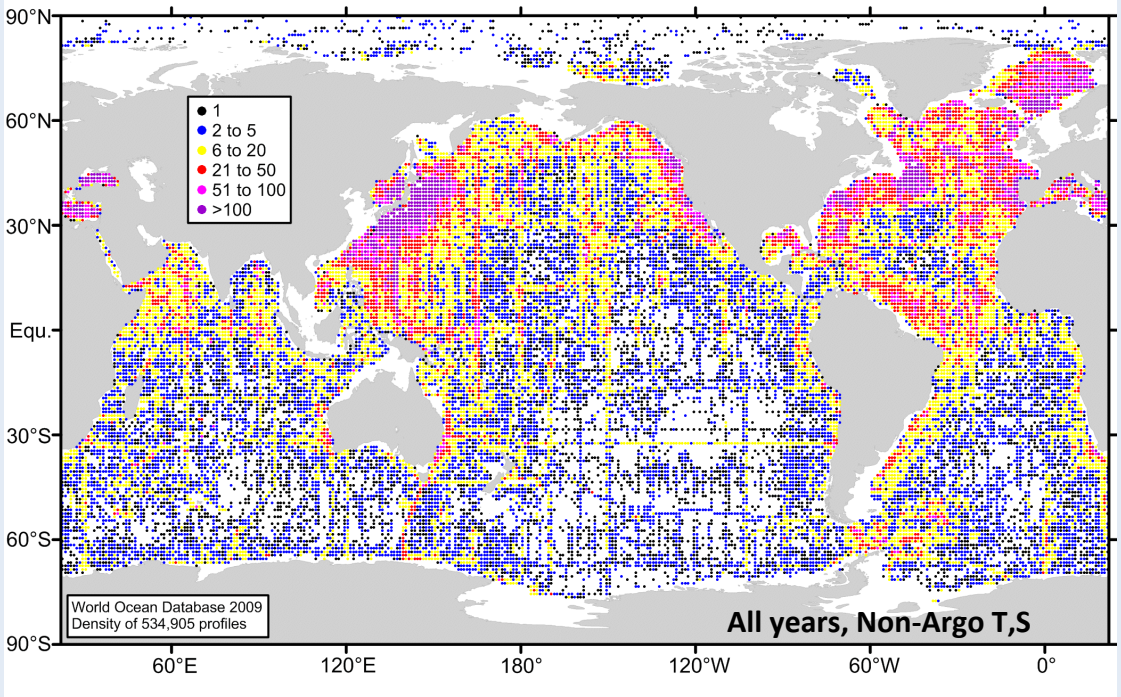




Cost of an Argo T,S profile is ~ $170.

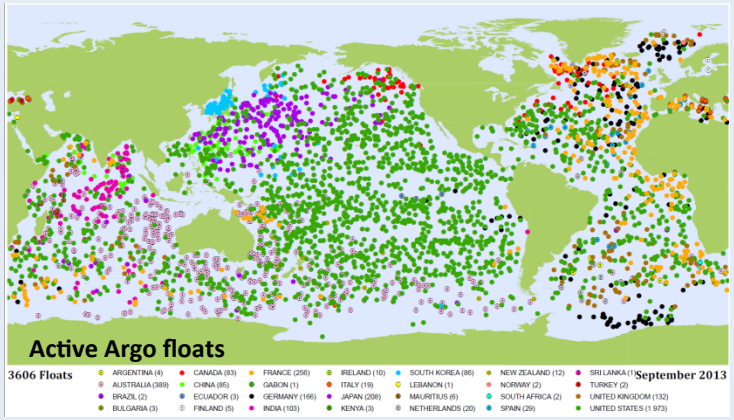
Typical cost of a shipboard CTD profile ~$10,000.





Argo's 1,000,000th profile was collected in late 2012, and 120,000 profiles are being added each year.

Global Oceanography

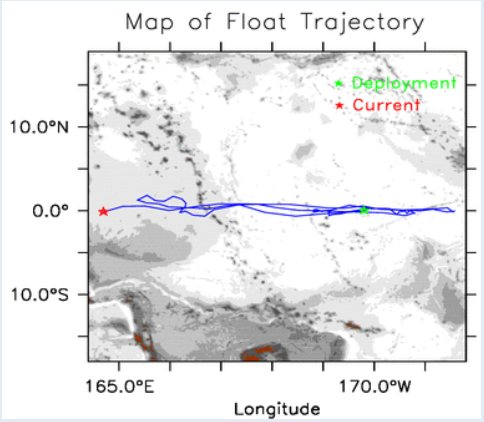


Global-*scale* Oceanography

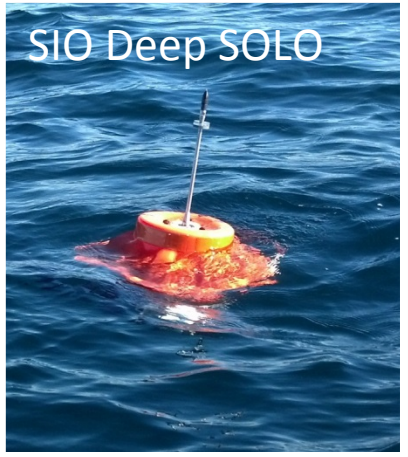
Float technology improvements

New generation floats (SOLO-II, Navis, ARVOR, NOVA)

- Profile 0-2000 dbar anywhere in the world ocean.
- Use Iridium 2-way telecoms:
  - Short surface time (15 mins) greatly reduces surface divergence, grounding, bio-fouling, damage.
  - High vertical resolution (2 dbar full profile).
  - Improved surface layer sampling (1 dbar resolution, with pump cutoff at 1 dbar).
- Lightweight (18 kg) for shipping and deployment.
- Increased battery life for > 300 cycles (6 years @ 7-days).



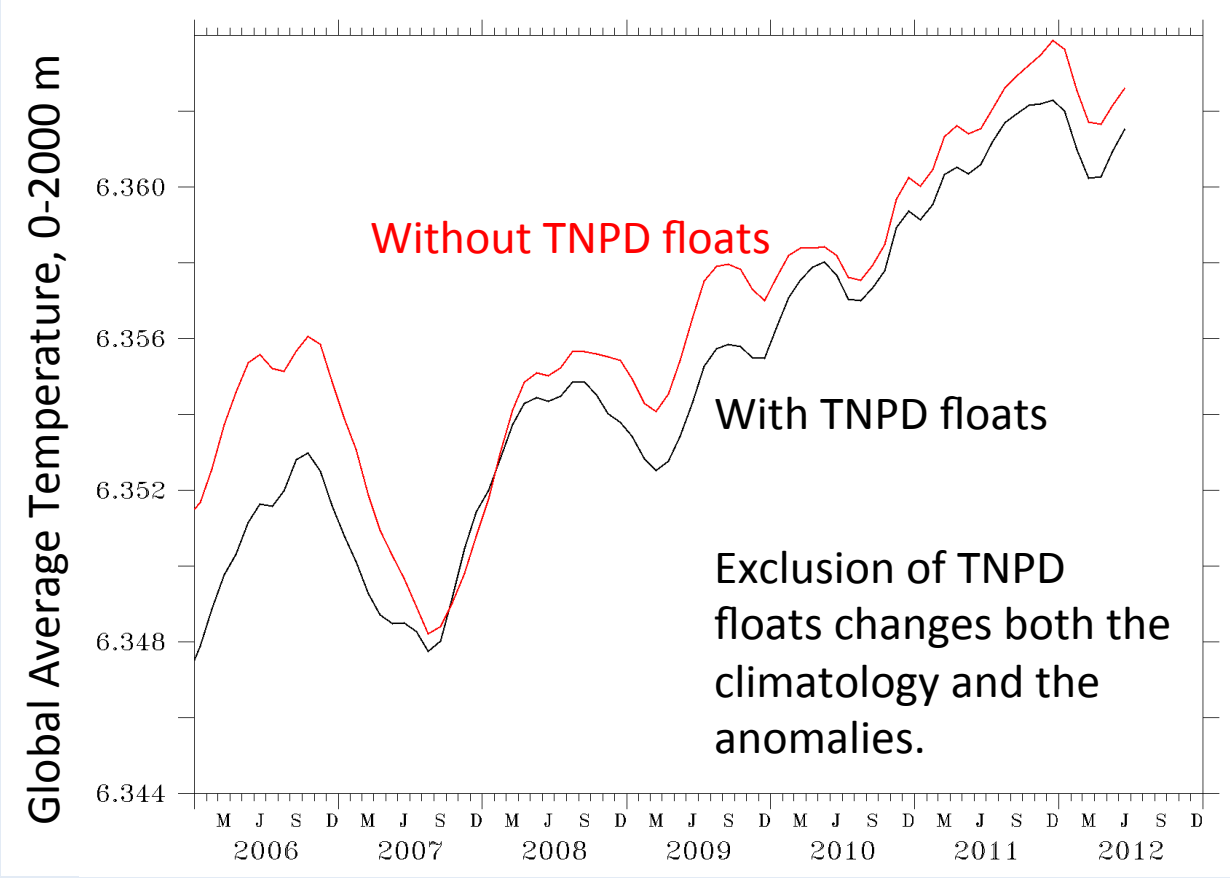
SOLO-II, WMO ID 5903539 (left), deployed 4/2011. Note strong (10 cm/s) annual velocities at 1000 m

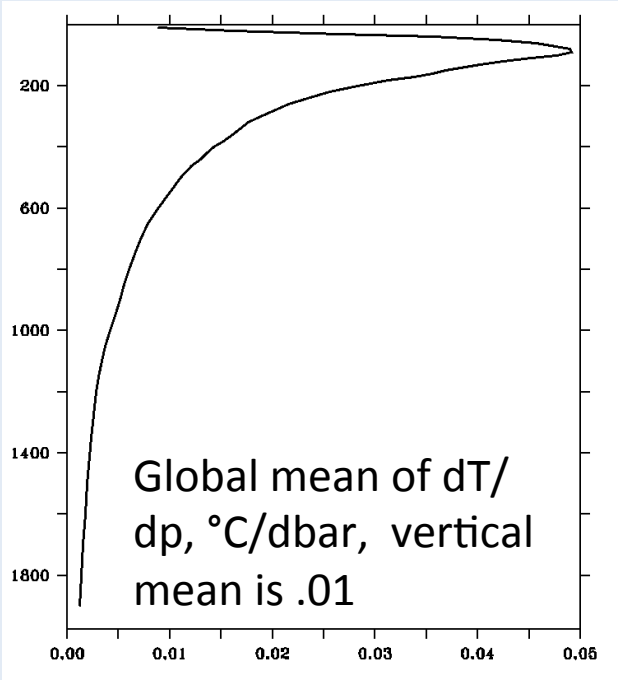


This Deep SOLO completed 65 cycles to 4000 m and is rated to 6000 m.

Issues for ocean heat content: Measurement error

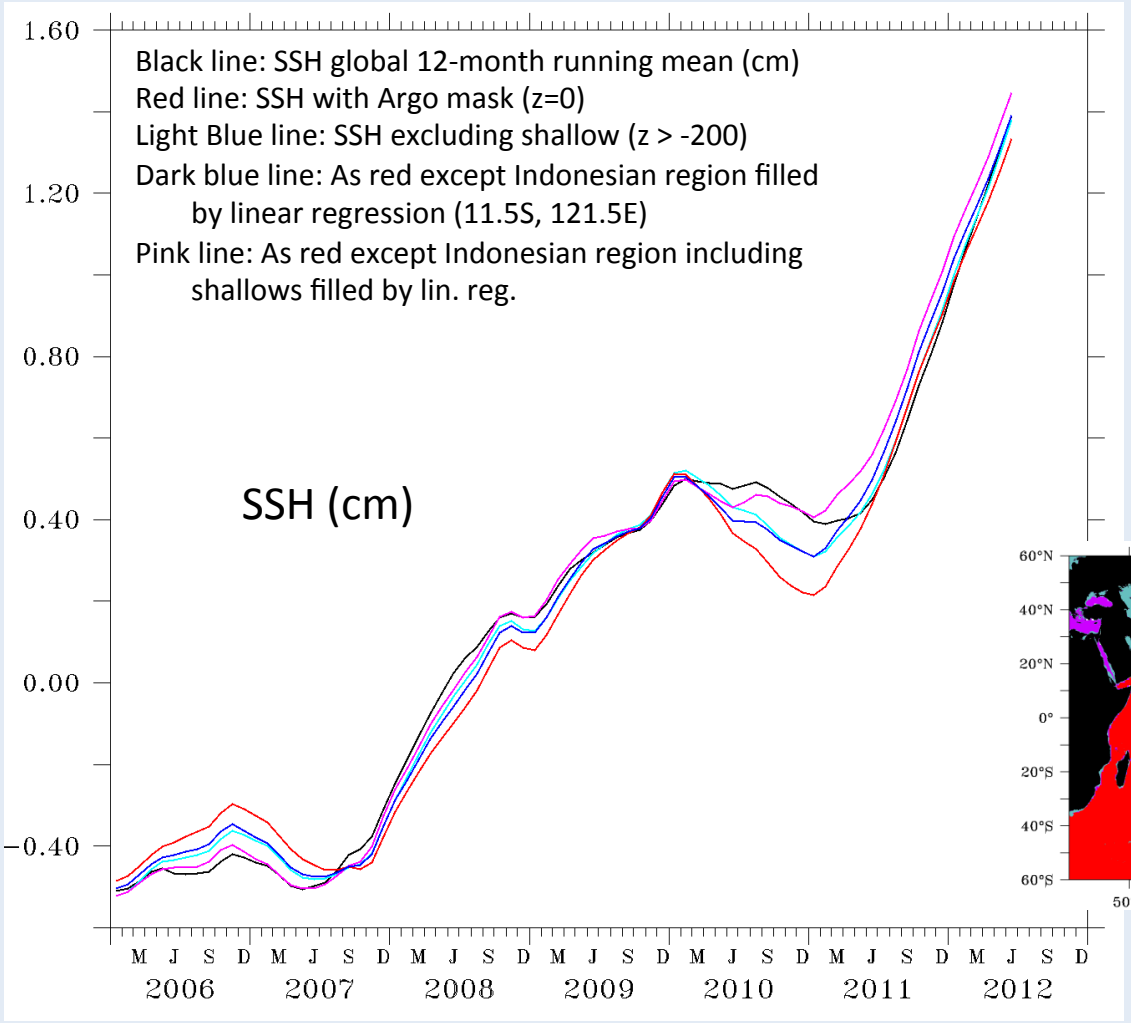
- Argo depth errors are much less than XBT, but not perfect.
- Manufacturers spec is ± 2 dbar in pressure, ± .002°C in temperature, so pressure error dominates.
- A float firmware defect (Truncated Negative Pressure Drift, TNPD) in APEX floats, in addition to a manufacturing problem (oil micro-leak) in Druck pressure sensors, led to unknown pressure errors in an identified set of Argo profiles.
- The float firmware has been corrected, and the affected float cycles are labelled TNPD.



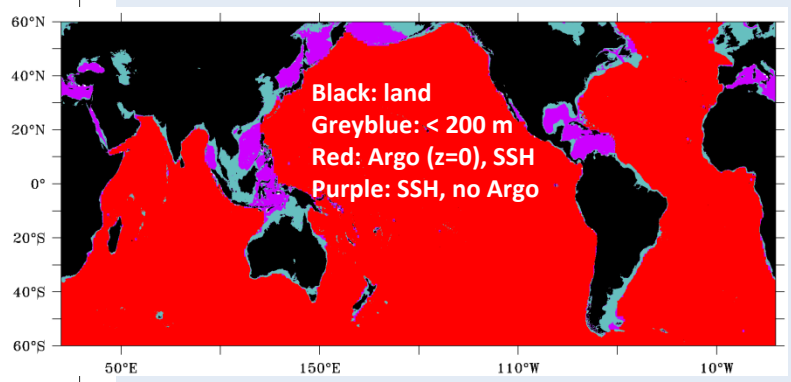


Issues for ocean heat content: Coverage bias

- Argo does not cover some marginal seas and shallow regions.
- Interannual variability in the Indonesian region can have a substantial impact on global average.
- Here, SSH is used as a proxy to illustrate the impact of Indonesian seas on the global mean.



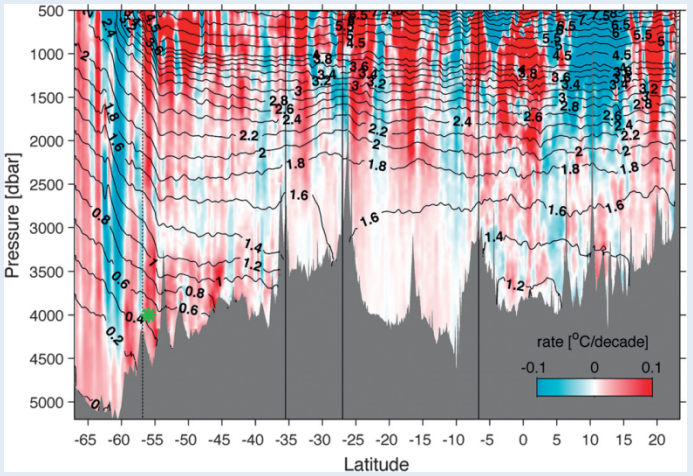
Regions not sampled by Argo, especially SE Asian seas, can impact heat storage on interannual timescales, less so in decadal trends.



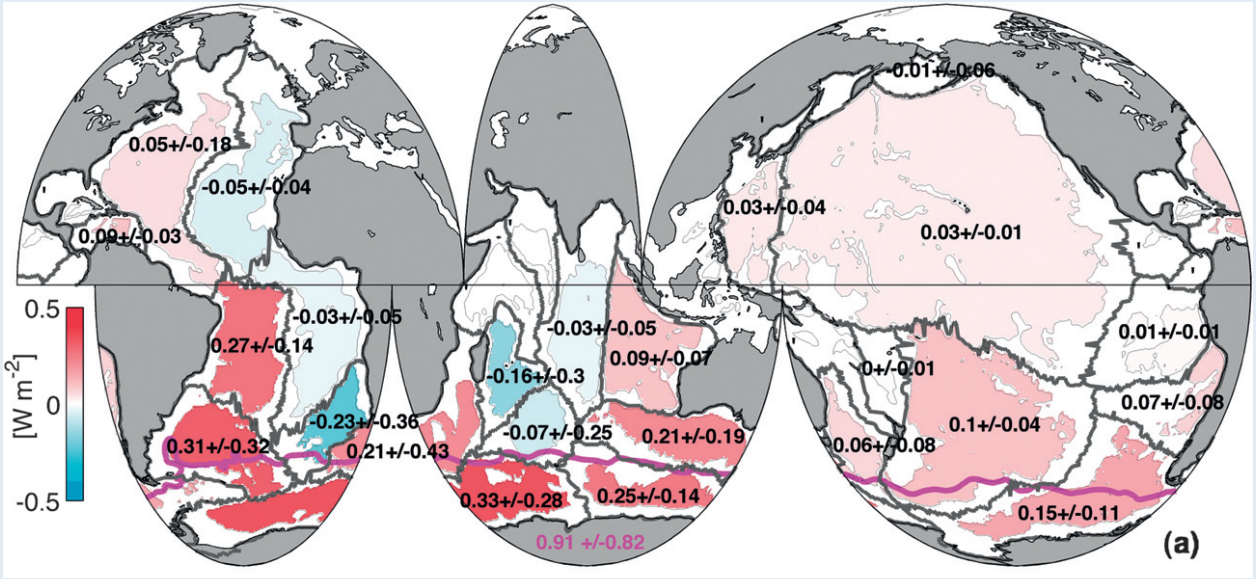
Issues for ocean heat content:

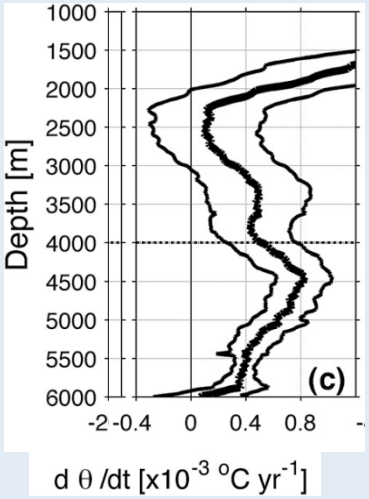
The deep ocean

- The present Argo array samples to 2000 m.
- Analysis of repeat hydrography indicates significant bottom-intensified, multi-decadal warming.
- Prototype Argo floats have 6000 m capability.



Above : Temperature trend along an eastern Pacific transect (Purkey and Johnson, 2010)



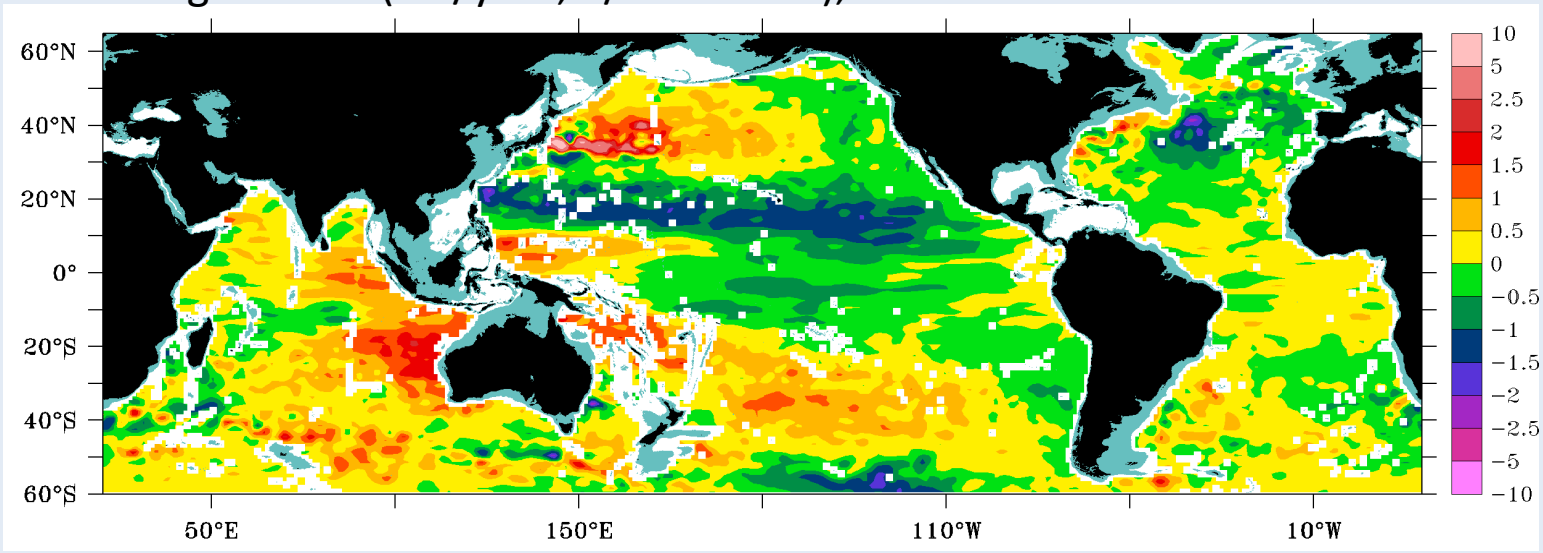


Purkey and Johnson (2010) estimate the rate of warming below 4000 m, and 1000 – 4000 m south of the Sub-Antarctic Front, regionally (left) and globally (right)

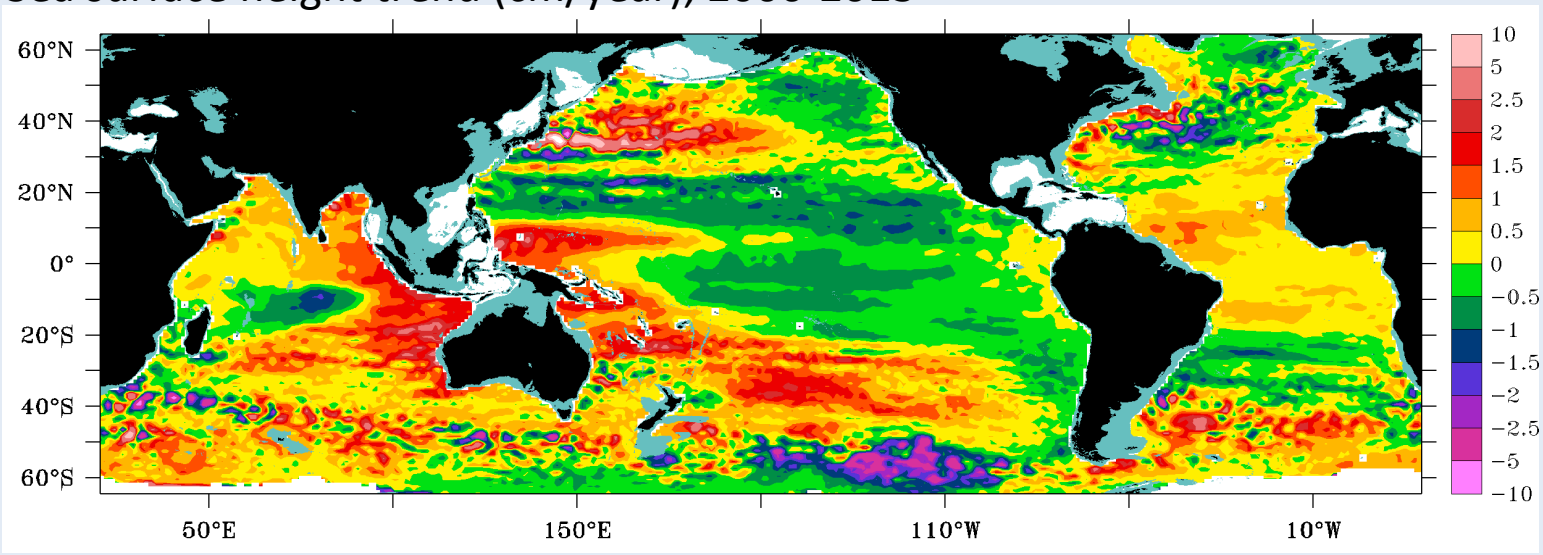
Deep (> 2000 m) warming contributes 0.1 W/m2 (average over Earth surface area)

Sea level and heat content trends are strongly regional, mainly due to temperature changes, often caused by wind-forcing.

Steric height trend (cm/year, 0/2000 dbar), 2006-2013

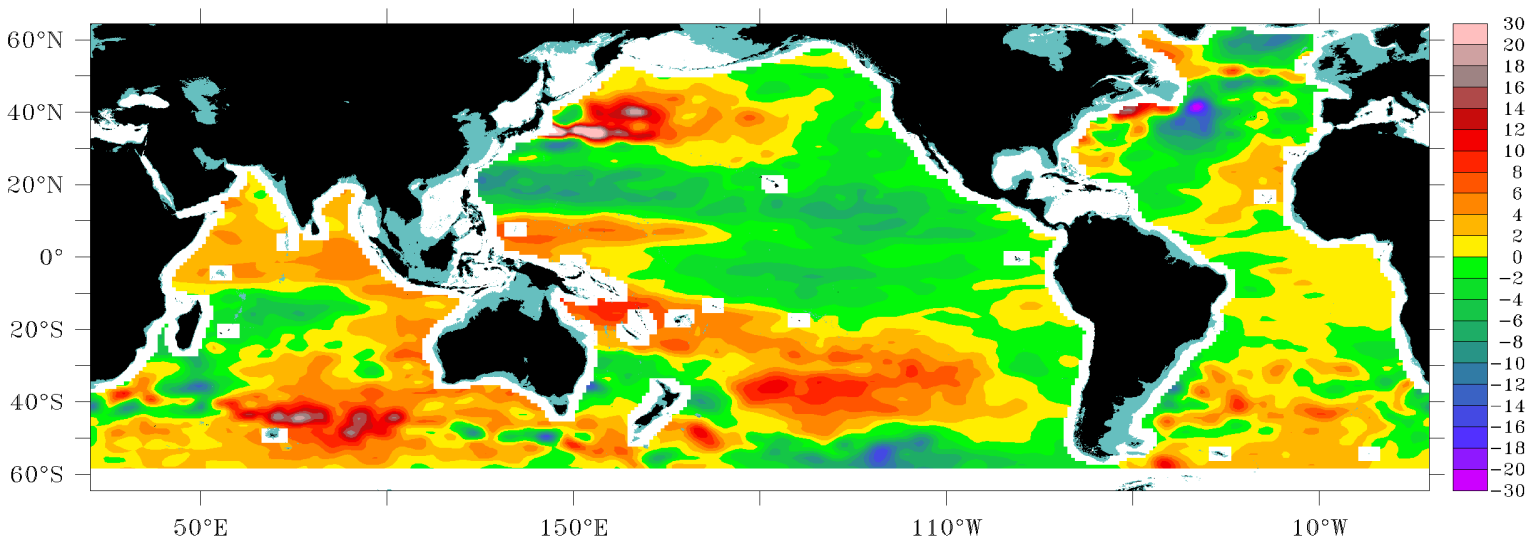


Sea surface height trend (cm/year), 2006-2013

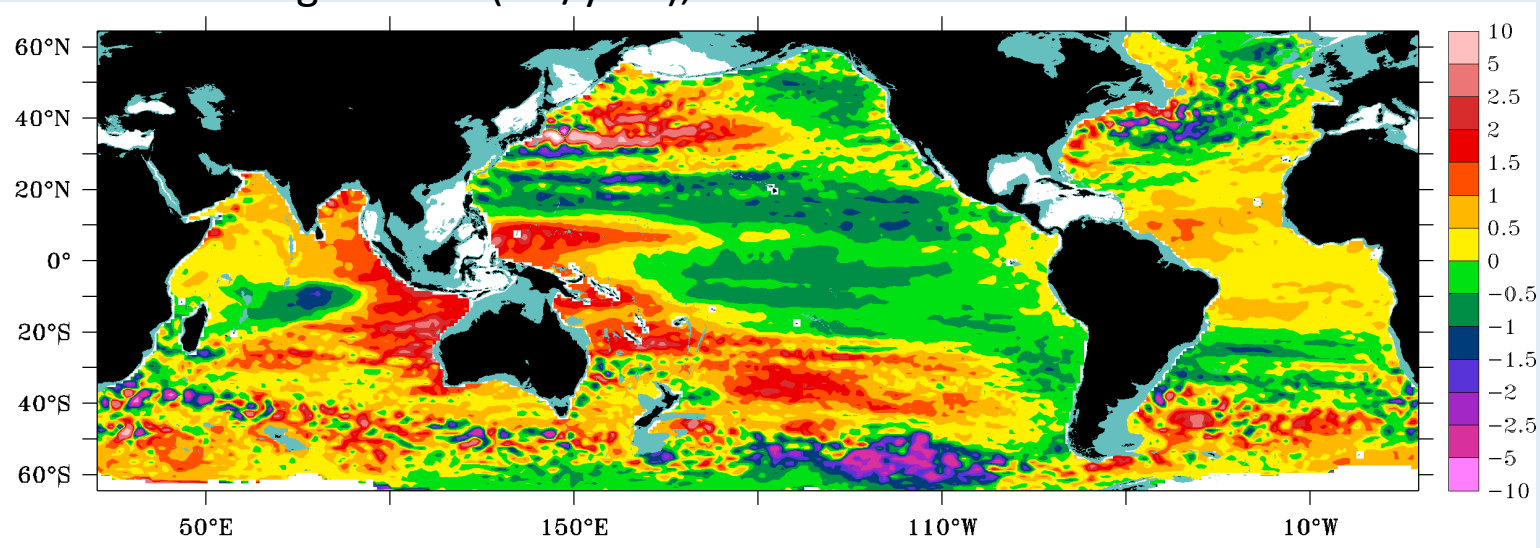


Temperature changes extend below 2000 m. Deep Argo needed!

Heating rate (W/m^2, 0/2000 dbar), 2006-2013

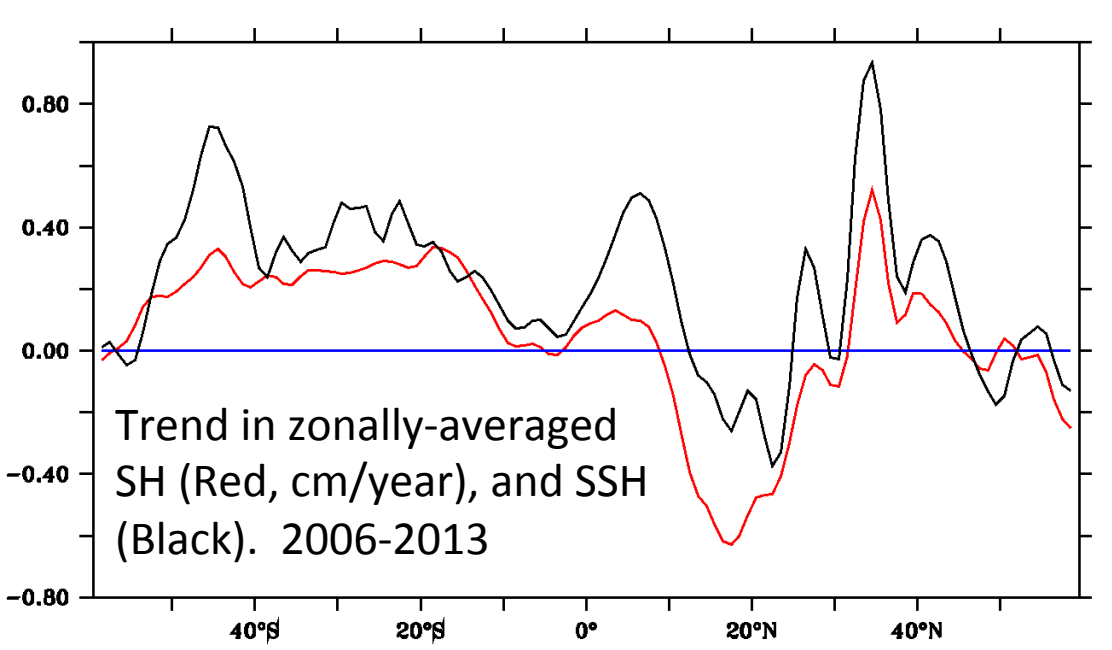


Sea surface height trend (cm/year), 2006-2013

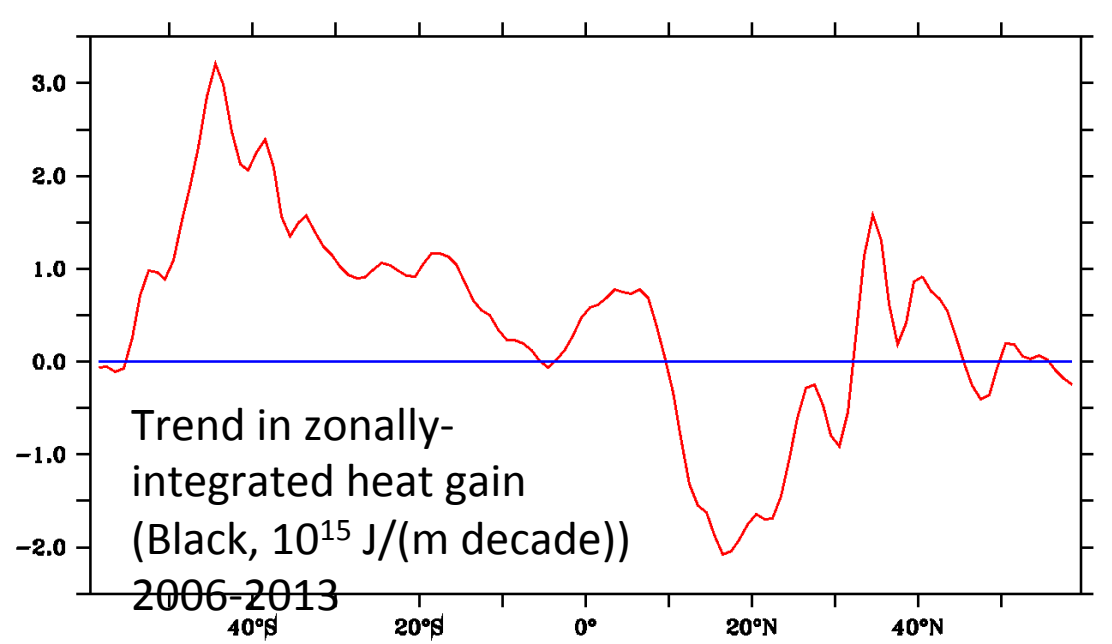


Note the strong hemispheric asymmetry.

The southern hemisphere dominates the increases in SH, SSH, and heat.

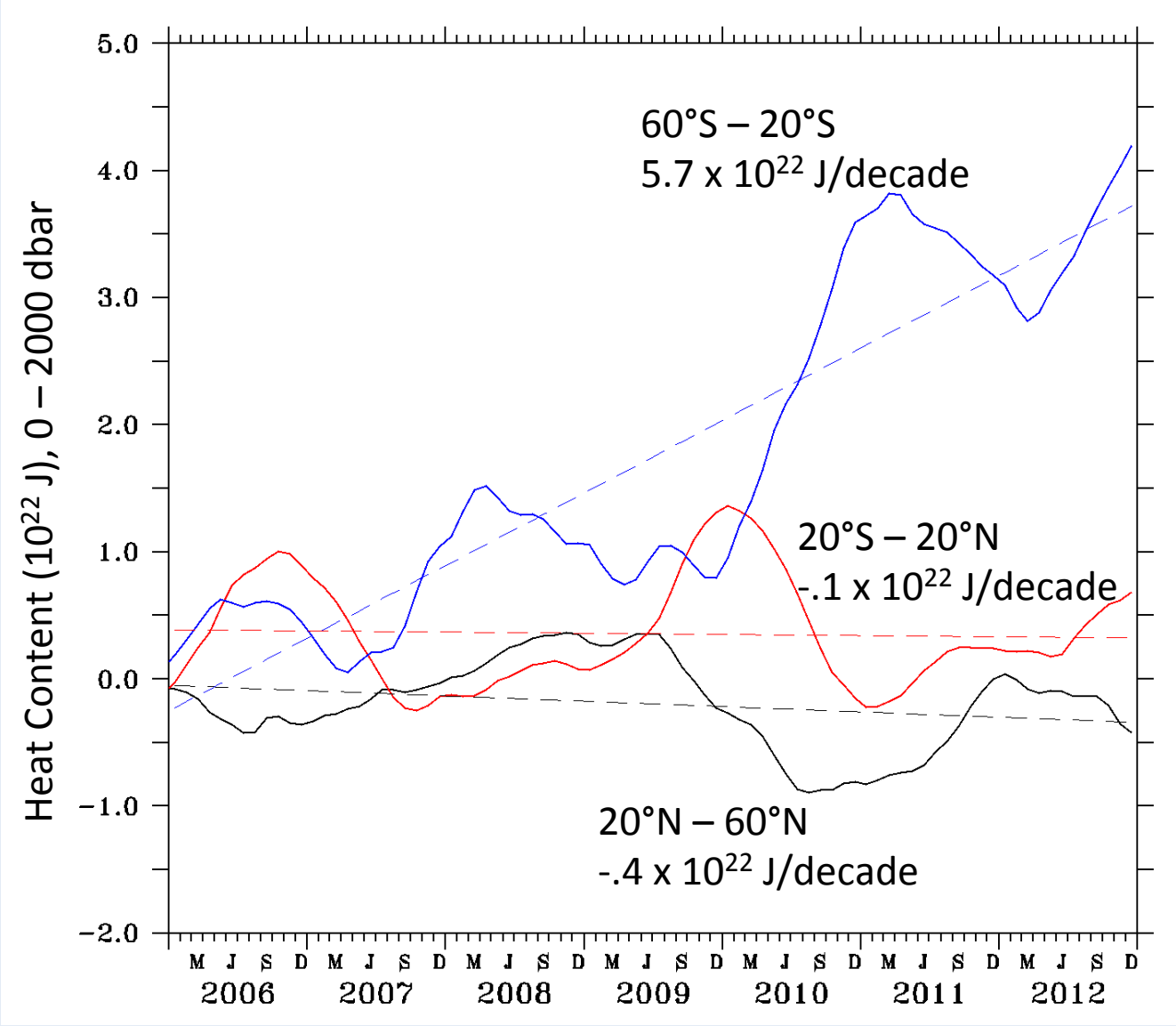


The SSH trend exceeds the SH trend by about 0.2 cm/year, fairly uniformly.

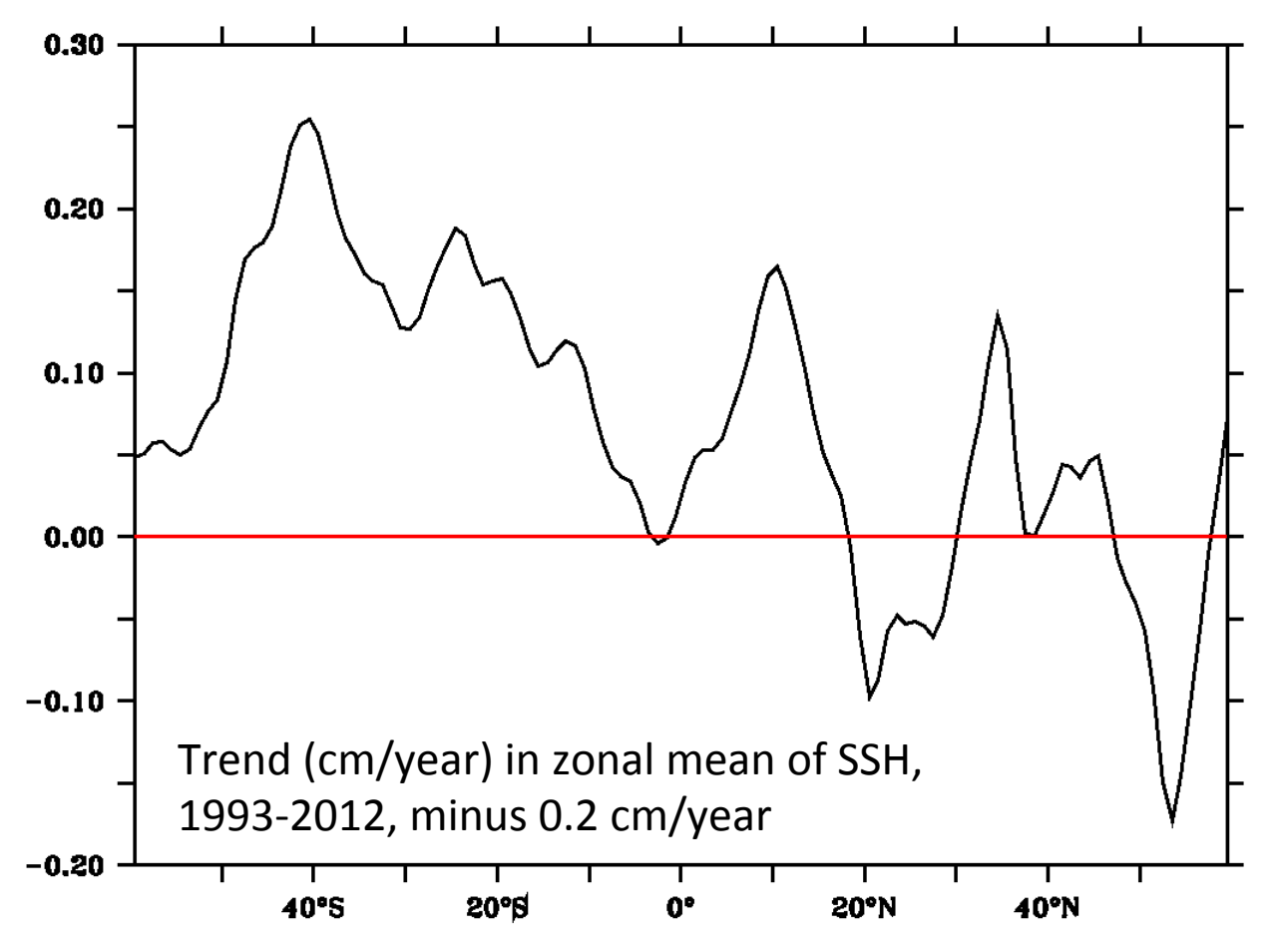


The hemispheric asymmetry is magnified in zonally *integrated* heat gain (due to the large area of southern hemisphere oceans).

All of the heat gain during the Argo era is in the southern latitudes.

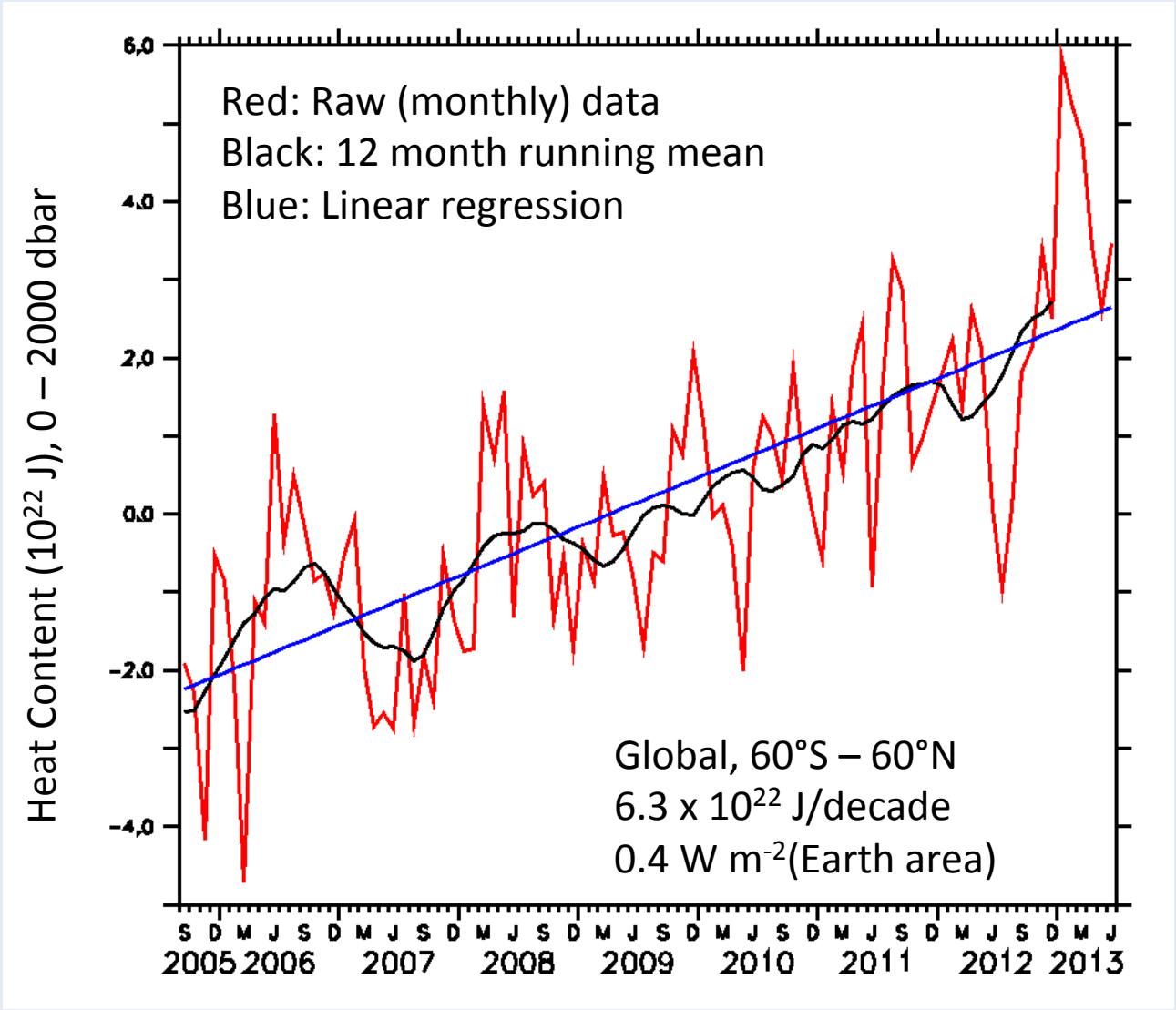


The hemispheric asymmetry is also seen in the 20-year SSH record:



Heat gain over the period from 1993 to the present is also dominated by the region south of 20°S (Sutton and Roemmich, 2011)

Ocean heat content measured by Argo.



Von Schuckmann and Le Traon (2011), 0-1500 m, 2005-2010, 0.4 W m^{-2} ±0.1 for Earth area

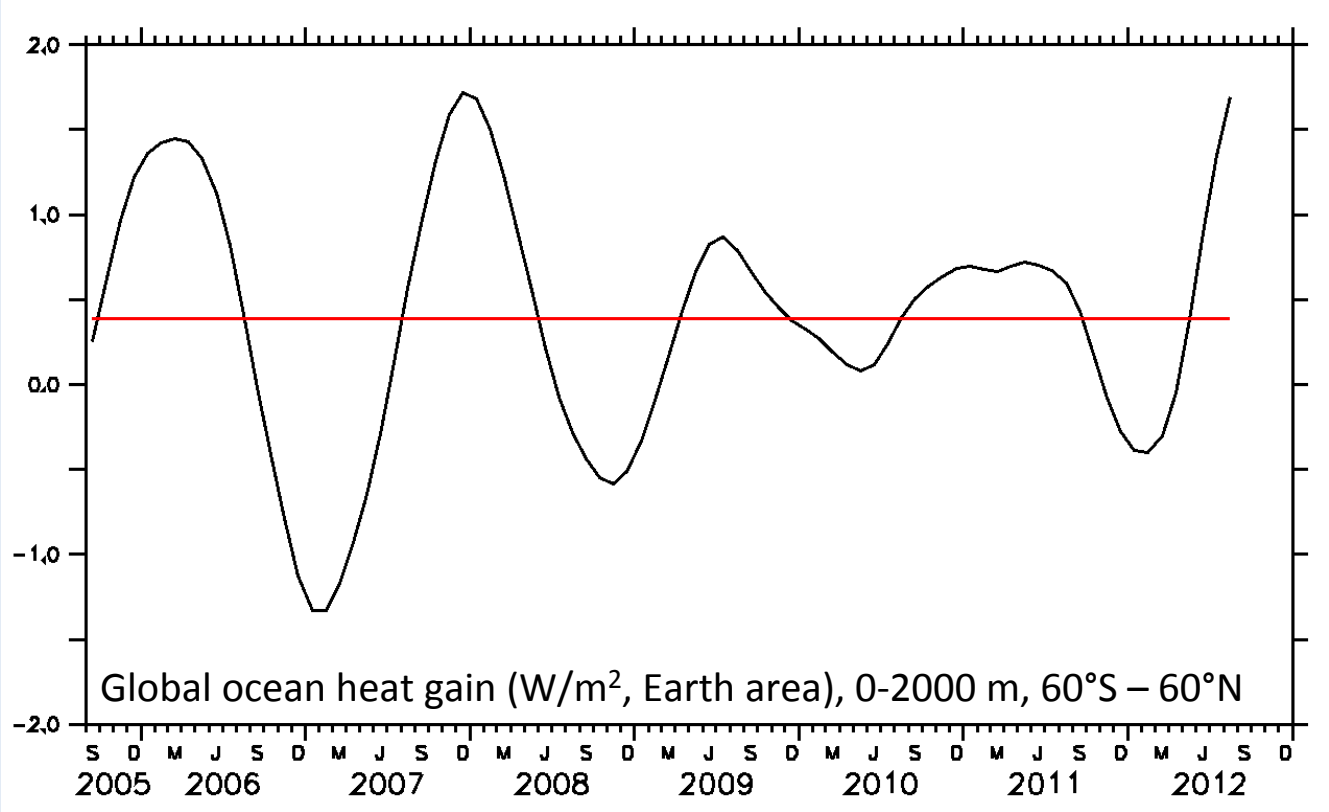
Lyman et al (2012), 0-700 m, 1993-2008: 10 x 10^{22} J/decade, 0.6 W/m^2 for Earth area

Levitus et al (2012), 0-2000 m, 1955-2010: 4.4 x 10^{22} J/decade, 0.27 W/m^2 for Earth area.

Roemmich et al (2012), 0-1500 m, 1872-2010: 0.2 W m^{-2} (lower bound) for Earth area

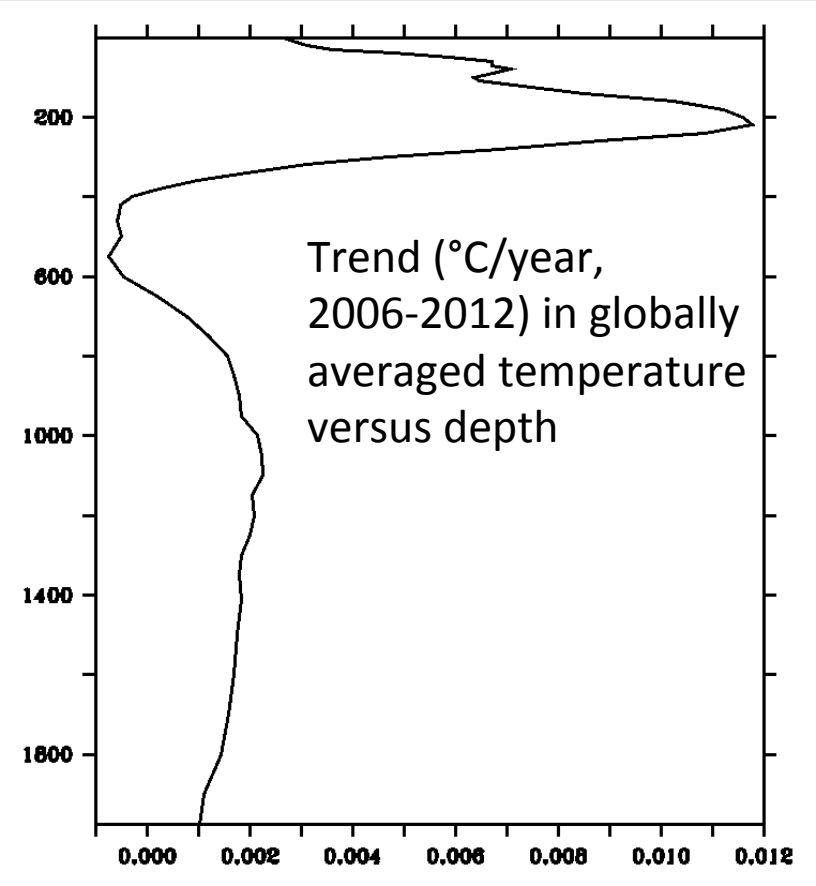
Heat gain during the Argo era *may* be lower than the decade preceding Argo, but is very similar to the 50-year trend, and the 138-year Challenger-to-Argo difference.

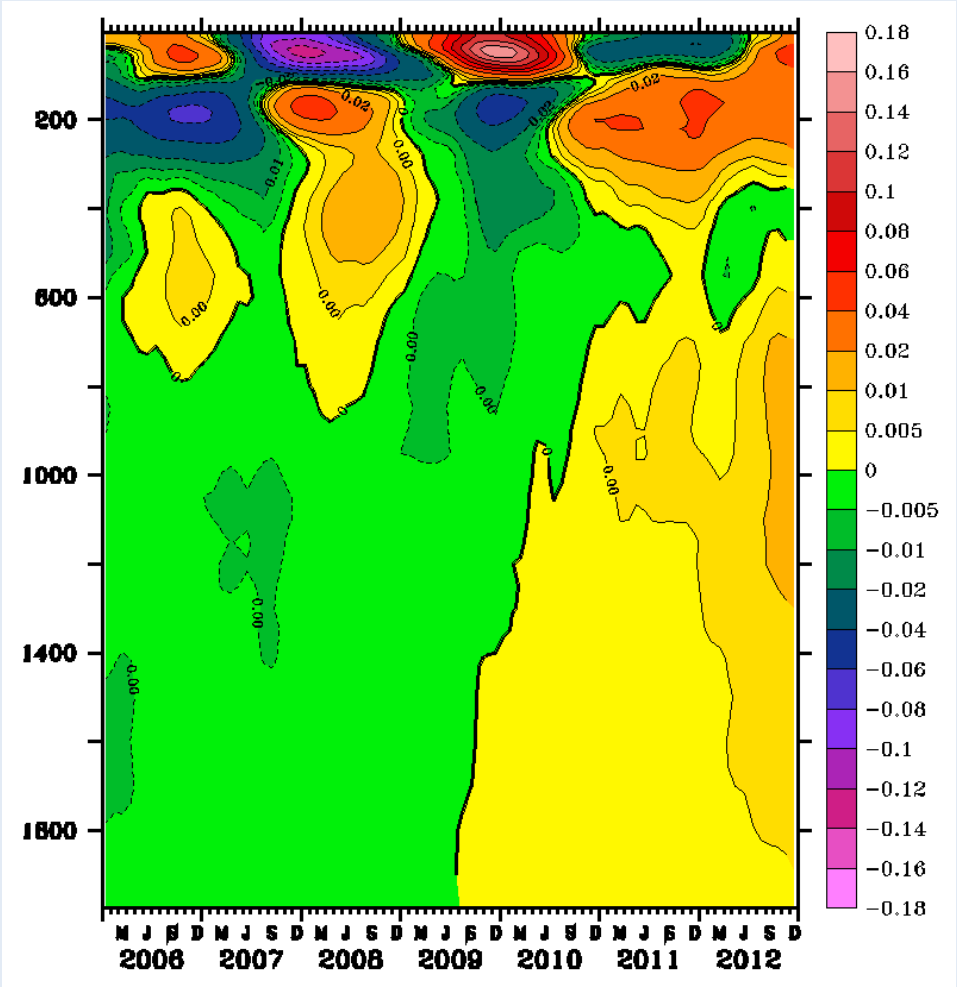
Ocean heat gain measured by Argo.



(i) No adjustment for Indonesian seas
(ii) Results are sensitive to smoothing parameters

Temperature variability and trend measured by Argo.



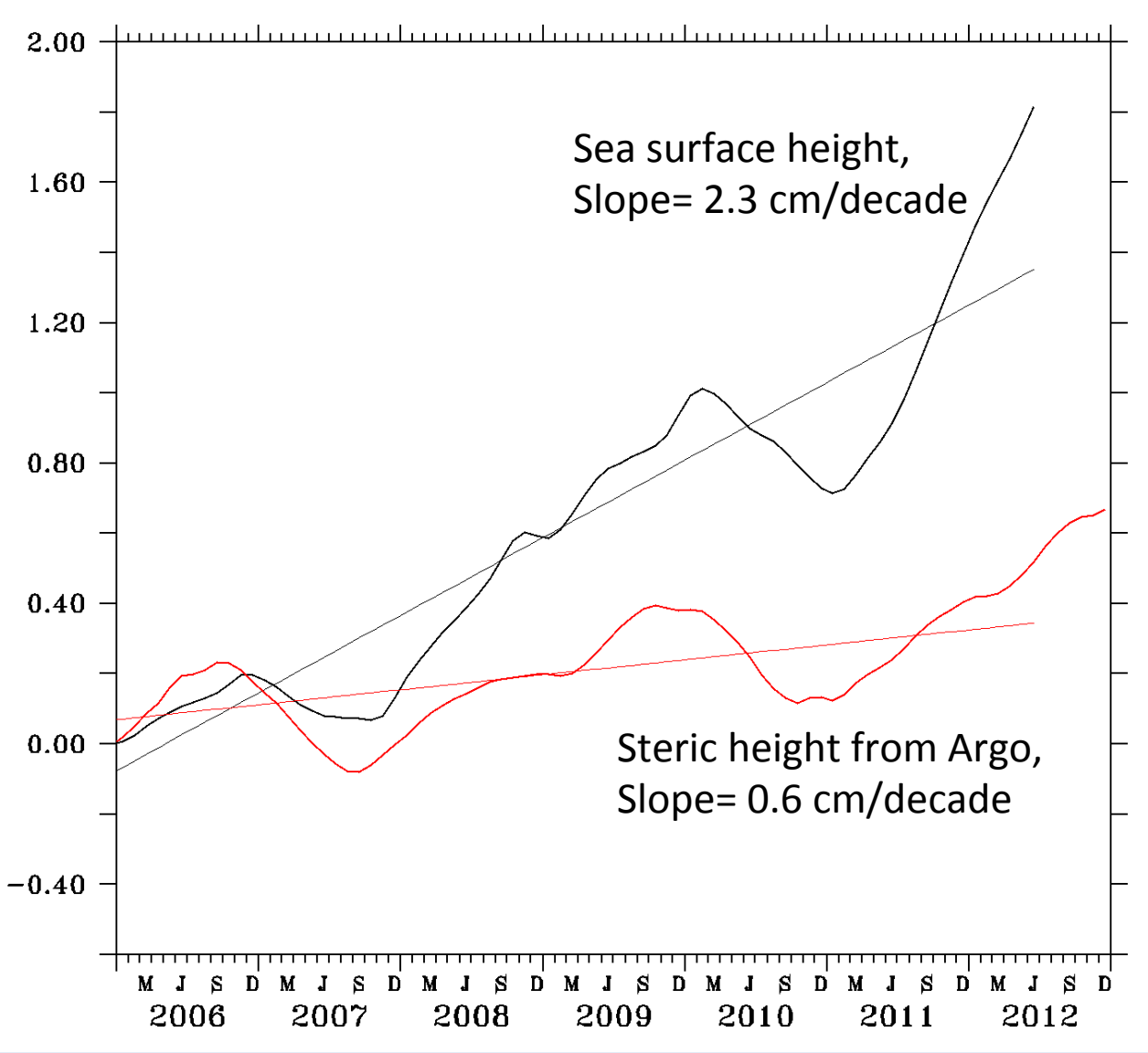


Time-series of globally averaged temperature anomaly (°C) versus depth

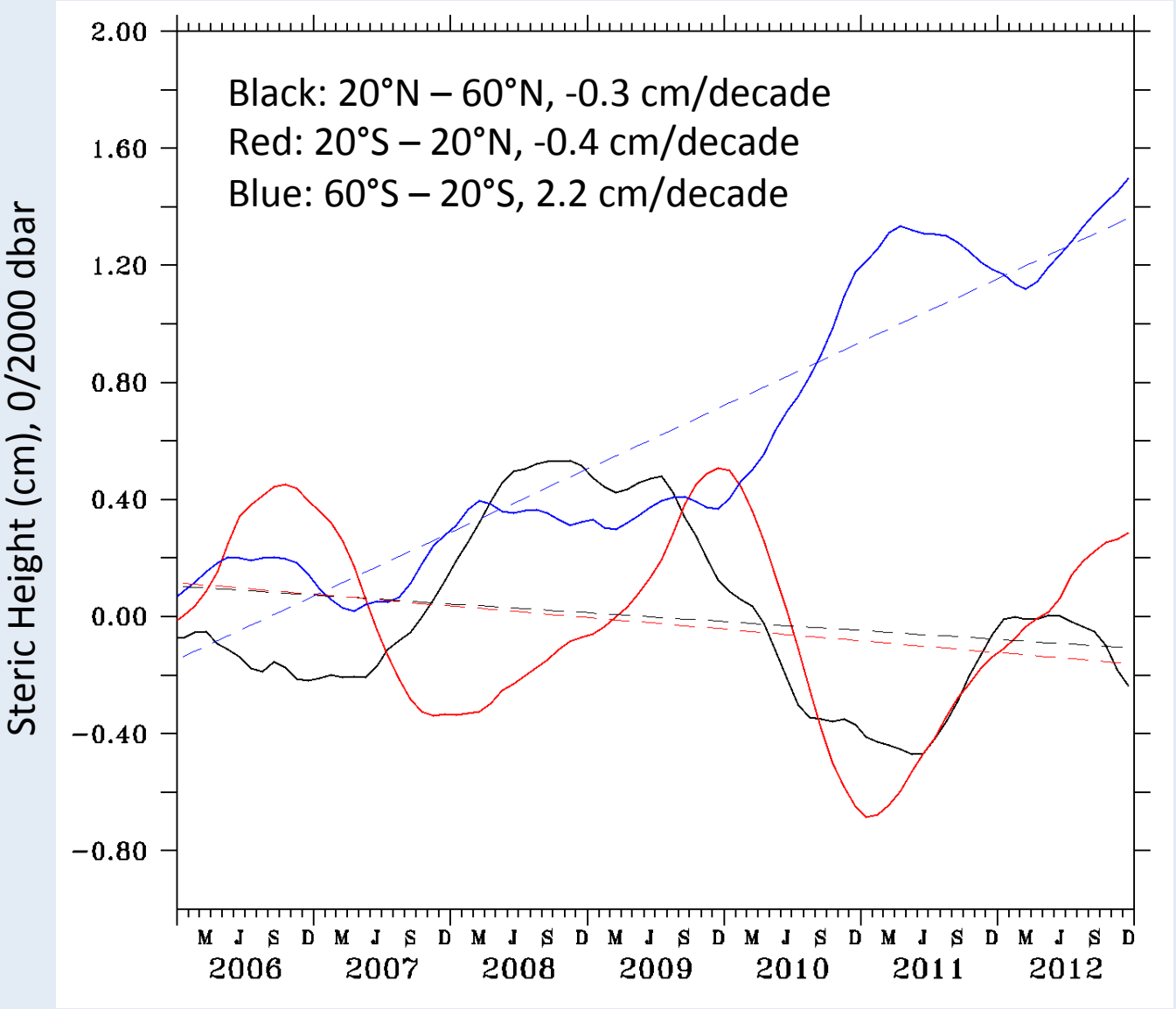
Much of the interannual variability in globally-averaged upper ocean temperature is associated with ENSO (Roemmich and Gilson, 2011)

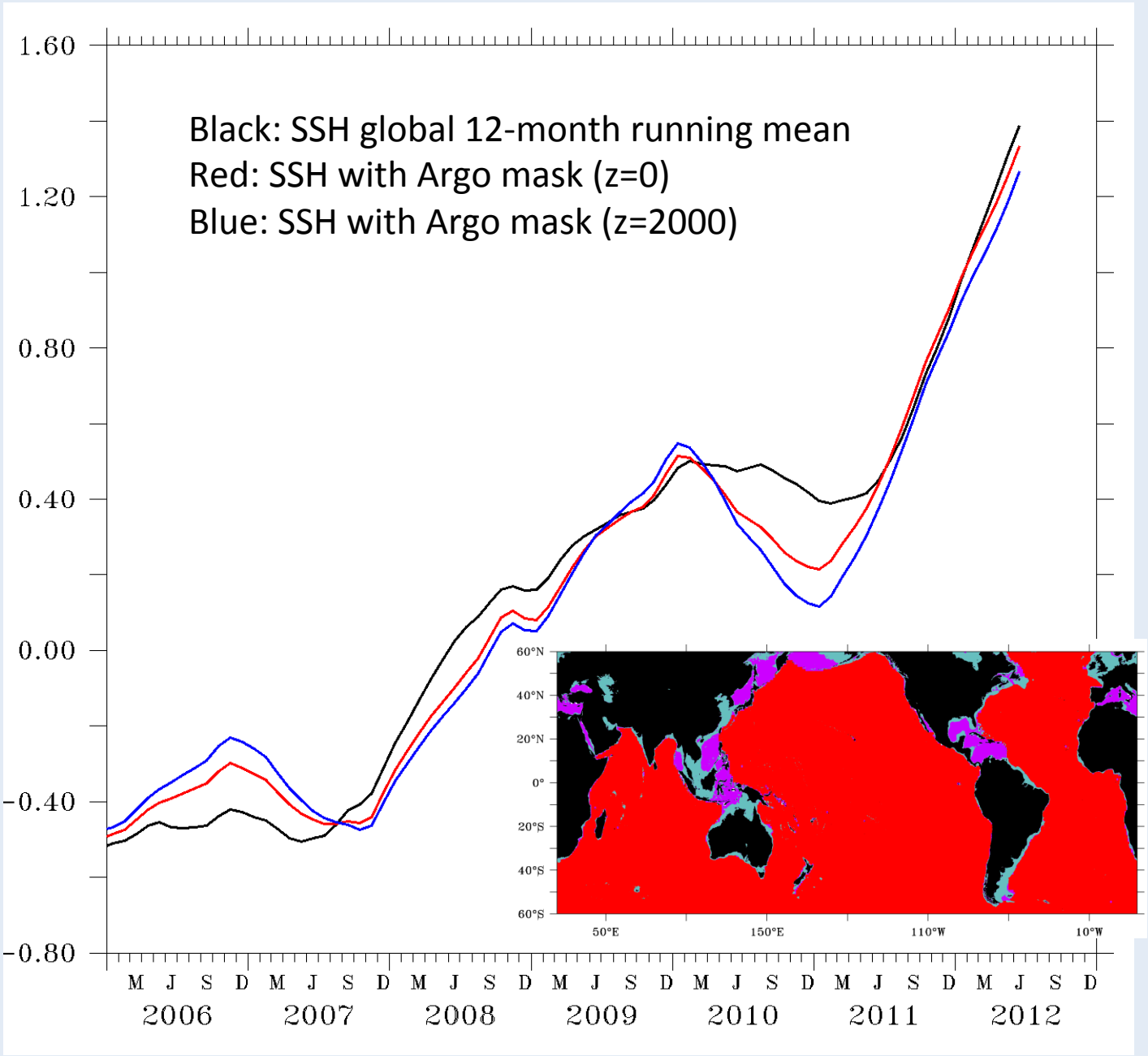
Summary

- Argo systematically measures ocean temperature globally, except in some marginal seas and on continental shelves.
- Issues for global ocean heat content estimation: measurement errors, coverage bias, the deep ocean.
- All of the heat gain 2006-2013 is south of 20°S, and the same is likely for the more sparsely sampled period 1993-2008.
- Ocean heat gain, averaged over the Earth's surface area is 0.4 W/m^2, 0-2000 m 2006-2013, with about 0.1 W/m^2 added by the deep ocean below 2000 m. This is similar to previous 50-year and longer estimates.
- Further investigations (sensitivity to climatology, mapping technique, domain) and longer Argo time-series will yield more accurate estimates, including interannual variability.
- Deep Argo (to the ocean bottom) is needed to close heat and sea level budgets, and Deep Argo floats now exist. Input is welcome on the design of the Deep Argo array.


2.00
1.60
1.20
0.80
0.40
0.00
−0.40
Sea surface height,
Slope= 2.3 cm/decade
Steric height from Argo,
Slope= 0.6 cm/decade
M J S D M J S D M J S D M J S D M J S D M J S D M J S D
2006
2007
2008
2009
2010
2011
2012

All of the net steric height gain during the Argo era is in the southern latitudes.




Black: SSH global 12-month running mean
Red: SSH with Argo mask (z=0)
Blue: SSH with Argo mask (z=2000)
1.60
1.20
0.80
0.40
0.00
-0.40
-0.80
M J S D M J S D M J S D M J S D M J S D M J S D M J S D
2006 2007 2008 2009 2010 2011 2012
60°N
40°N
20°N
0°
20°S
40°S
60°S
50°E
150°E
110°W
10°W
Black: land
Greyblue: < 200 m
Red: Argo (z=0), SSH
Purple: SSH, no Argo